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Assessment of Constraints on Space Shuttle Launch Rates

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Assessment of Constraints on Space Shuttle Launch Rates

Committee on NASA Scientific and Technological Program Reviews

Commission on Engineering and Technical Systems

National Research Council

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16. Abstract (Limit: 200 words) In the 1990 time frame it is expected that a 4-orbiter fleet would marginally support 24 space shuttle launches per year, and a 5-orbiter fleet, 30 launches per year. However, the launch rate would be reduced by extended mission durations, frequent repairs, long overhaul periods or contingencies incapacitating an orbiter for a prolonged period. Of the major components of the STS, the external tank (ET) is the only one for which firm planning is in place to meet launch rates of 24 and above. Improved refurbishment facilities for the Solid Rocket Booster (SRB) and additional units and spares for the Space Shuttle Main Engine (SSME) are needed.

Facility capability estimates are provided for ground turnaround, cargo handling, flight training and flight operations. Emphasizing the complexity of the STS systems and the R&D nature of present flight experience, it is concluded that the most prominent constraints in the early growth of the STS as an operational system may manifest themselves not as shortages of investment items such as the ET or SRB, but as inability to provide timely repairs or replacement of flight system components needed to sustain launch rates.

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Space Shuttle; Space Transportation System; Constraints on Launch Rates; External Tank Production Facilities; Solid Rocket Booster Refurbishment; Facilities Supporting STS Flight Operations

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Space Shuttle, Space Transportation System; External Tank, Solid Rocket Booster; Space Shuttle Main Engine; Orbiter; OPF; VAB; MLP; Launch Pad; Firing Room; VPF, Shuttle Mission Simulator; STA; Shuttle Carrier Aircraft

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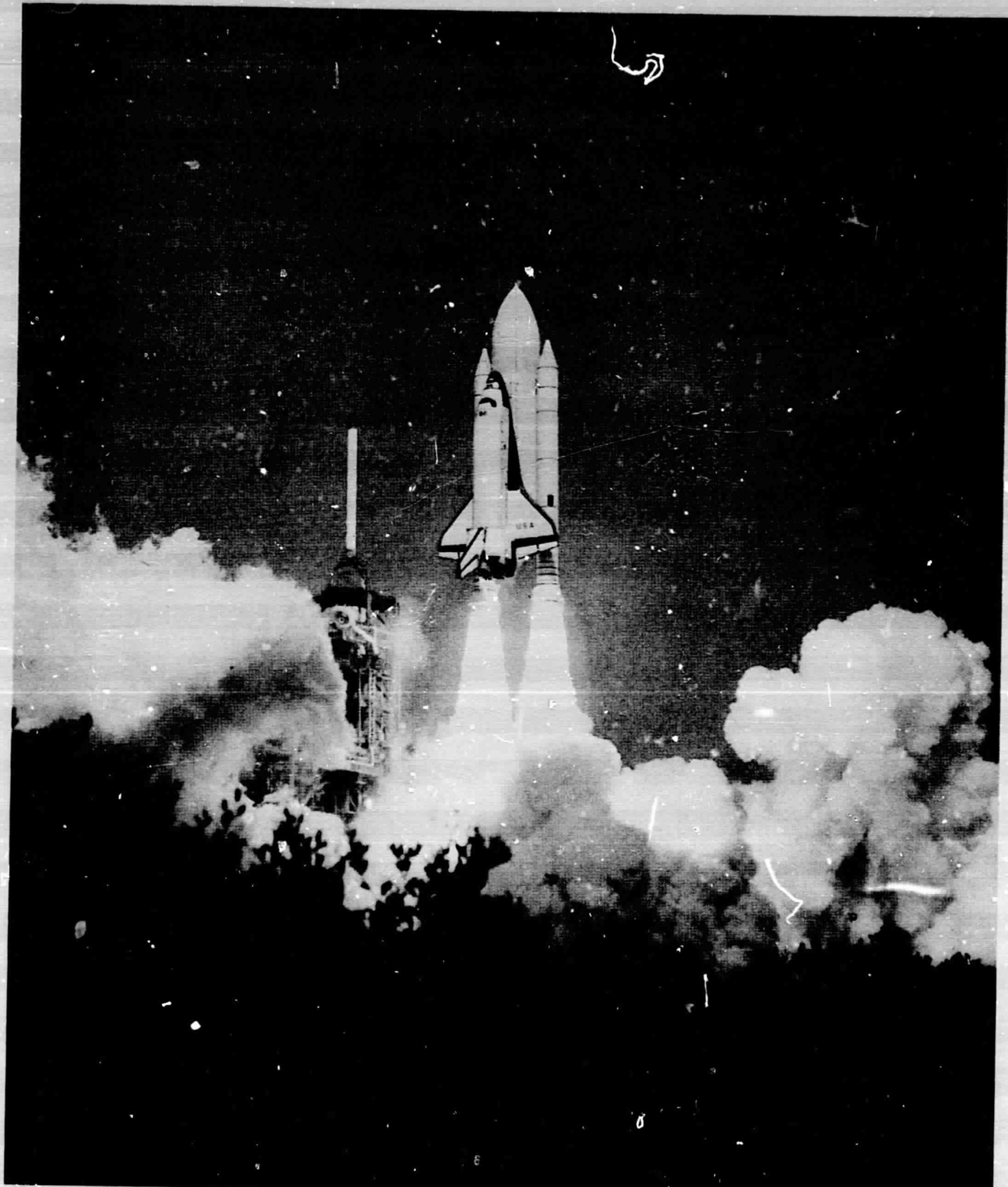
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PANEL TO ASSESS CONSTRAINTS ON SPACE SHUTTLE LAUNCH RATES

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Preface

The Committee on NASA Scientific and Technological Program Reviews was created by the National Research Council in June 1981 as a result of a request by the Congress of the United States to the National Aeronautics and Space Administration that it establish an ongoing relationship with the National Academy of Sciences and the National Academy of Engineering for the purpose of providing an independent, objective review of the scientific and technological merits of NASA program changes whenever the Congressional Committees on Appropriations so direct.[1]

When a review is requested, the Committee is called into action to set the terms of reference, select a panel of experts to carry out the task, and review the resulting report before publication.

Two tasks have been undertaken to date. The first was a review of alternative versions of the International Solar Polar Mission, a joint venture between NASA and the European Space Agency, undertaken in 1981.[2] The second was a review of proposed reductions in the FY 1983 NASA Aeronautics Research and Technology Program, undertaken in 1982.[3]

The third task, which is the subject of this report, resulted from a request by the Congressional Committees on Appropriations to the NASA Administrator in late October 1982 for an assessment of constraints on space shuttle launch rates, with emphasis on External Tank production (Appendix A). The Committee met on November 18, 1982, to establish terms of reference (Appendix C) for the review based on the Congressional request and to nominate a panel to undertake the task. This group had to be knowledgeable in aerospace engineering, defense procurement and logistics, airline operations, production and

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[1]Congressional Conference Report 96-1476, November 21, 1980.

[2]The International Solar Polar Mission: A Review and Assessment of Options, National Academy Press, Washington, D.C., September 1981.

[3]Aeronautics Research and Technology: A Review of Proposed Reductions in the FY 1983 NASA Program, National Academy Press, Washington, D.C., July 1982.

shipment of large structures, the NASA Space Transportation System (STS), the federal policymaking process, and current executive branch policy. In appointing such a group of individuals to make scientific and technical assessments, it is essential that most have a high degree of expertise in the subject of the study. Because such individuals are apt to appear to have a potential for bias, every effort was made to achieve a balance in backgrounds and attitudes of the panelists in order to present as objective a report as possible.

The short period during which the review had to be undertaken put severe demands on the Chairman and members of the panel, who deserve much credit for their effective and timely response.

Norman Hackerman
Chairman, Committee on NASA Scientific
and Technological Program Reviews

I

Introduction

The space shuttle consists of a reusable Orbiter vehicle, two recoverable Solid Rocket Boosters (SRB), and an expendable External Tank (ET) that carries the liquid propellant for the Orbiter's three main engines. Management of the Space Shuttle Program is shared by NASA Headquarters and three NASA Centers--the Johnson Space Center (JSC) in Houston, Texas; the Marshall Space Flight Center (MSFC) in Huntsville, Alabama; and the Kennedy Space Center (KSC) in Florida.

NASA Headquarters is responsible for overall policy and direction. The Johnson Space Center is responsible for program management, flight control, and development of the Orbiter. The Marshall Space Flight Center's responsibilities include development of the External Tank, Solid Rocket Booster, and the Space Shuttle Main Engine (SSME). The Kennedy Space Center serves as the launch and landing site. In addition, the Department of Defense will operate a launch and landing site at Vandenberg Air Force Base (VAFB) in California.

Prime contractors are Rockwell International's Space Division for the Orbiter, its Rocketdyne Division for the Space Shuttle Main Engine, and Martin Marietta Aerospace for the External Tank. The Marshall Space Flight Center has retained primary management for the Solid Rocket Booster, with assembly and checkout operations subcontracted to United Space Boosters, Inc., and the Solid Rocket Motor subcontracted to Thiokol Corporation.

The current NASA Mission Model calls for 24 space shuttle launches per year in 1988, 30 in 1990, and 40 in 1992.

The charge to the Panel from the Committee on NASA Scientific and Technological Program Reviews (Appendix B) calls for an estimate of yearly launch rates given a 4- and 5-Orbiter fleet, an assessment of the capabilities and known constraints associated with launch rates of 18, 24, 30, and 40 per year, and the specific capability of External Tank production to meet these rates.

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II

Approach

The Panel met on December 15-16, 1982, and on January 10-13 and March 8-9, 1983. The first and third meetings were held at the National Academy of Sciences in Washington, D.C. The second meeting included a visit on January 10 to the Martin Marietta-operated Michoud Assembly Facility in Louisiana, where the External Tank is produced, and to the Kennedy Space Center in Florida on January 11-13 for briefings and a tour of facilities associated with space shuttle turnaround, including the Vehicle Assembly Building, the Orbiter Processing Facility, Launch Pad A, and the Vertical Processing Facility. On March 28, 1983, a representative from the Panel visited the space shuttle launch facilities at Vandenberg Air Force Base, California.

During the course of its meetings the Panel was briefed by NASA personnel from Headquarters, the Johnson Space Center, the Marshall Space Flight Center, and the Kennedy Space Center, as well as personnel from Martin Marietta Michoud Division, United Space Boosters, Inc., and the Thiokol Corporation. A list of briefing personnel is given in Appendix D.

The Panel took account of other National Research Council studies that deal with the space shuttle, which include the Assembly of Engineering's reports, Technical Status of the Space Shuttle Main Engine, March 1978, and Second Review--Technical Status of the Space Shuttle Main Engine, February 1979, as well as the General Accounting Office's report, Issues Concerning the Future Operation of the Space Transportation System, GAO/MASAD-83-6, December 28, 1982, and the Congressional Research Service's report on United States Civilian Space Programs 1958-1978, January 1981.

The charge to the Panel requests the following information:

1. An estimate of the range of the number of annual STS flights, given a 4- and 5-Orbiter fleet, accounting for normal turnaround time and contingencies.
2. An overview of the capabilities needed to support these estimated flight rates, including rates of 18, 24, 30, and 40 a year, with a survey of known constraints or limiting factors.
3. An estimate of the facility modifications and requirements needed to match production of External Tanks to the above annual

shuttle flight rates, including consideration of learning curve effects.

4. An estimate, based on available data, of the costs associated with the External Tank facility modifications, including any additional costs that might be incurred by modifying the facility to first support 24 flights a year and then later increasing the capability to support a higher flight rate.

5. An estimate of the date that External Tank production would be available to support each of the flight rates determined above.

In considering the charge, and specifically space shuttle capabilities and constraints, the Panel explored in detail Orbiter turnaround functions and procedures, hardware, software, payloads, propellants, flight training, general services, and logistics.

The most difficult question to answer in terms of time and flight estimates concerned contingencies, covering the gamut from minor perturbations to meeting flight schedules to major disasters, all of which are statistically possible but unquantifiable.

The issue of space shuttle utilization and the potential market for reusable-launch-vehicle payloads was not addressed.

The responses to the charge focus on the 1990 time frame.

The Panel wishes to express its appreciation to the many members of the NASA staff who provided valuable information for the study and facilitated the work of the Panel in every way.

III

Launch Rates for 4- and 5-Orbiter Fleet

In 1986 a parallel line of launch facilities is expected to come online at the Kennedy Space Center (KSC), and launch and landing facilities are expected to become operational at Vandenberg Air Force Base (VAFB). The Orbiter fleet, presently consisting of the Columbia (OV-102) and the Challenger (OV-099), will grow to 4 with the addition of the Discovery (OV-103), expected to be delivered in late 1983, and the Atlantis (OV-104) in 1984. The earliest availability of a fifth Orbiter, if funded in FY 1984, would be 1987.

The determinants that establish the range of annual STS flights are Orbiter ground turnaround duration; on-orbit flight duration; routine Orbiter recovery; the number of days and shifts worked per week; the level of logistics support, including spares; Orbiter downtime for major periodic maintenance; and flight support functions.

To date, NASA has very limited experience in turnaround of the Orbiter and no experience on which to base estimates for Orbiter downtime for major periodic maintenance. Hence, all estimates of Orbiter fleet capacity are based on program planning and projections of improvements in flight hardware design, reductions in requirements, improvements in ground support equipment, and enhancements to facilities.

The Panel reviewed each of the elements that support the operations: the production of External Tanks (ET); the recovery and refurbishment of the Solid Rocket Motors (SRM) and Boosters (SRB); the ground processing of the Orbiter, including its rocket engines and subsystems; the integration of the Orbiter, ET, and SRB into a space shuttle preparatory to movement to the launch pad; and finally, the logistic systems that support these operations.

These elements and functions are fully discussed in Chapters IV and V. In the following estimate of normal turnaround time it is assumed that all components and capabilities, including fuels and cargo, are available at the time they are needed in the process of preparing the space shuttle for launch.

TURNAROUND AND LAUNCH RATE ESTIMATES

The Panel examined NASA's space shuttle Orbiter capability studies, as well as the most current NASA turnaround data and projections. The phases in the turnaround process from a landing on the KSC Space Shuttle Landing Facility to the next launch include: tow of the Orbiter to the Orbiter Preparation Facility for inspection, maintenance, and horizontal cargo loading if required; movement to the Vehicle Assembly Building for mating with the External Tank and Solid Rocket Boosters on the Mobile Launch Platform; roll out of the space shuttle to the Launch Pad for servicing; vertical cargo loading if required; checkout, and launch. A detailed discussion of shuttle turnaround operations is given in Appendix E.

Turnaround Time

Optimistic and conservative time estimates for each step in the turnaround process are shown in Figure 1 and summarized in Table I for the 1990 timeframe.

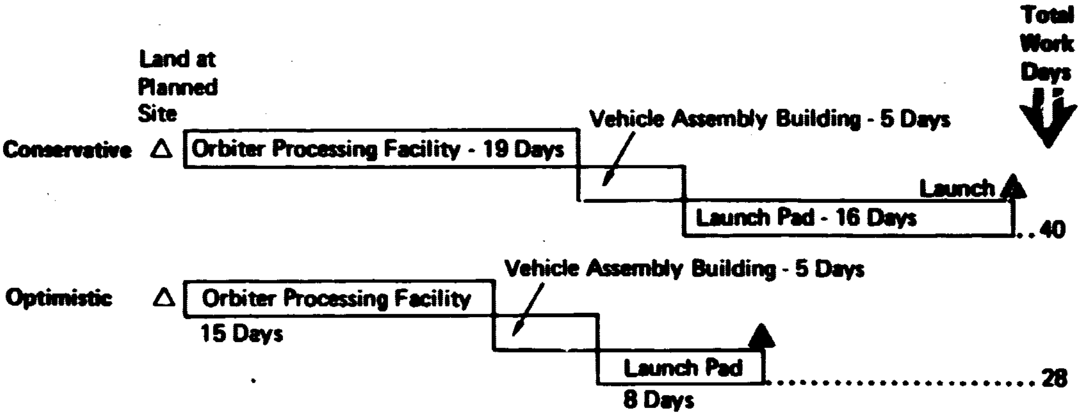

FIGURE 1 Range of Orbiter Turnaround Durations (Circa 1990)

In the breakdown of time in Figure 1 the number of days in the Vehicle Assembly Building does not change, since the mating, power and fuel line connection operations can be expected to be relatively routine and trouble-free, whereas there is clearly a potential for more extended periods of time in the Orbiter Processing Facility for refurbishment, repair, and component replacement, and even longer extensions on the pad associated with preparation for launch.

Achievement of a 28-day ground turnaround requires NASA to improve the process at a 70 percent learning rate.* The on-orbit mission duration of 5 days represents the average of the expected durations attendant to Spacelab, DoD, and multipayload deployment missions. This assessment also recognizes the need for Orbiter downtime for major periodic inspection and maintenance after every so many flights. Each STS flight stresses the Orbiter structural and thermal protection systems much closer to design limits than does a normal flight for commercial or military aircraft. In light of this fact and in the absence of experience, NASA's initial estimate of an average of 5 months of downtime after every 25 flights was considered acceptable. However, this rate should be approached progressively; i.e., major inspection and maintenance should be conducted more frequently on early flights until confidence is gained. When allowance for the 25/5 downtime is included in the effective availability of an Orbiter, the operational flights per year per Orbiter are reduced from 7.5 to about 6.6.

TABLE I Orbiter Flight Capacity

Estimate	Ground Turnaround	Average Mission Duration	Major Periodic Maintenance Downtime	Average Flights per Year per Orbiter 5/3[3]
Conservative	40 Work Days	7 Days	15/5 Mo.[1]	4.6
Optimistic	28	5	25/5 Mo.[2]	6.6

[1]After every 15 flights an Orbiter is taken down for 5 months for major periodic maintenance.
[2]After every 25 flights an Orbiter is taken down for 5 months for major periodic maintenance.
[3]Workweek is 5 days and 3 shifts per day.

The conservative case presumes ground turnaround improves to only 40 work days--about an 80 percent learning rate--from current experience of 94 work days (STS-5). The longer on-orbit duration of 7 days is based on the expectation that missions might be longer to compensate for fewer flights. Major periodic maintenance and inspection,

*This means that for each doubling of the numbers of launches, only 70 percent of labor hours are required for the later launch.

assumed to be more frequent, is scheduled to be conducted between every 15 flights. In this operating mode the average number of flights per year a single Orbiter can achieve is 4.6, based on a 5-day workweek. Only about one flight per year per Orbiter is added with a 7-day workweek.

Vandenberg Air Force Base Operations

The Orbiter turnaround durations estimated in Table I are based on KSC operations and do not apply to VAFB. Differences in launch facilities between KSC and VAFB constrain the latter to longer Orbiter turnaround time and, hence, lower utilization of the Orbiters assigned to be launched at Vandenberg. These differences could not be quantified because VAFB planning and estimates are in early stages. Initially, the turnaround at VAFB is projected to be about 60 days--4 to 5 flights per year--which can probably be reduced with time. For purposes of estimating STS fleet capacity, however, the Panel assumed that the lower utilization of the equivalent of one Orbiter at VAFB would correspond to 5 flights per year in the optimistic estimate and 4 flights per year in the conservative estimate. The range in space shuttle fleet capacity for both a 4- and 5-Orbiter fleet, accounting for the possibility of one equivalent Orbiter at VAFB, is shown in Table II.

TABLE II Space Shuttle Fleet Capacity

	Total Flights per Year 5-Day Workweek, 3 Shifts	
Estimate	4-Orbiter Fleet	5-Orbiter Fleet
KSC Launch Estimates		
Conservative	18	23
Optimistic	26	33
One Orbiter Equivalent at VAFB		
Conservative	17	22
Optimistic	25	31

Workweek Consideratons

As the space shuttle operations stabilize and mature, NASA plans to move toward a 5-day, 3-shifts-per-day workweek, both to reduce premium labor costs and to provide schedule buffers to better ensure on-time launches. With the weekends set aside, troubleshooting teams can recover from the schedule delays due to the normal problems attendant on any operational system. A scheduled 7-workday week was regarded as inefficient and undesirable for a protracted period because of its inevitable impact on flight safety.

Estimates of the average number of days of delay per mission for such reasons as routine vehicle and cargo troubleshooting, anomaly resolution, and launch holds for weather indicate that weekends may be required to absorb normal schedule disruptions. The proven ability to launch payloads on schedule clearly will be of great value to the user community. Thus, NASA's plan to move toward a 5-day workweek for space shuttle operations and use weekends for better schedule recovery appears wise.

IMPACT OF CONTINGENCIES ON FLIGHT RATES

The loss of, or major damage to, a single Orbiter in service or any number of other unfavorable conditions would preclude reaching estimated flight rates. Contingencies that could cause perturbations to shuttle scheduling can be placed in two categories--those with major impact on the schedule but without hazard to the program itself and major disasters involving hazards to the crew, to major elements of the flight hardware, or to ground facilities. The latter hazards are less susceptible to preplanning for recovery because of their possible safety or political impacts.

Those contingencies most difficult to assess include accidents, problems arising from contamination, and defense alerts. In addition, requirements are not known for future major configuration upgrades, extended missions, or missions requiring specific launch windows and/or extraordinary cargo preparation. Nevertheless, previous experience in both airline and military operations suggests contingencies will arise. The issue here is planning. In cases like this where the size of the fleet is small, development of a suitable data base to allow for contingencies is a matter of extreme difficulty.

Needless to say, in a complex system such as the STS there are many possible situations that might lead to difficulties and damage. Examples of some such contingencies that might be anticipated are discussed below.

Main Engine Component Failure

The main engines of the shuttle represent an ambitious approach to the boundaries of the present state of the art in materials, bearings, system design, and manufacturing precision and control. The demonstrated short life of the turbopumps (hydrogen and oxygen) and the recurrent problems in the combustors and nozzle skirts suggest that a sizable spares program will be required if no major life-improvement changes are made in these components. A spares and life improvement program needs to be activated and funded along with R&D programs to improve the life of critical SSME elements.

The possibility of major damage to the shuttle and to ground test facilities from engine component failures is high. Thus, thorough inspection prior to firings and launch, and preservation of existing facilities for main engine testing, are essential to maintain a predictable launch rate.

Solid Rocket Booster Limitations

The issue of production and refurbishment rates for solid rocket motors is discussed elsewhere. However, current facilities for handling and storing propellant segments at KSC limit the flight rate. The current amount of solid propellant handling within the VAB is a hazard that limits crew size and therefore launch rate.

Loss of solid propellant cases and attached hardware during recovery operations has already occurred and probably can be expected again during high rate operations. This potential loss of hardware is compounded by plans for introduction of some light weight, filament wound cases that will produce a mixed inventory some of which will not be recovered and some of which may be too heavy for use on certain flights.

Failure of an Orbiter Major Structural Element

Some of the Orbiter's major structural elements could on occasion be loaded near or even to the failure limits. As an example, the landing gear loads may vary significantly because they are functions of Orbiter landing weight, landing speed, pilot technique and atmospheric turbulence conditions. The consequence of the failure of a critical element such as the landing gear could range all the way from minor repairs to a major accident and schedule delay.

Reduction or Loss of Control Power

The power system for the flight controls (hydraulic power source) consists of 3 auxiliary power units in the Orbiter and dual installation of similar power units in each Solid Rocket Booster. Although these light weight hypergolic-fueled hydraulic sources have been carefully developed and tested, the failure of one or more of these 7 units during a shuttle mission is possible. The results of an in-flight failure could range from the most probable, reduced control power with little liability to the schedule, to serious systems or Orbiter damage with major schedule implications.

Diverted Landings

A number of contingencies may cause the Orbiter to land at other than the planned return site. An example of such a contingency would be the necessity to divert due to a heavy rainstorm at the landing area. Such a contingency during high-rate operation will necessitate rapid retrieval without upsetting planned operations. This may well require an additional Shuttle Carrier Aircraft (SCA, a Boeing 747) and arrangements for transporting the handling and hoisting gear to the site. Further, there is an element of risk in relying on a single SCA, especially at higher flight rates, since the SCA itself is subject to damage or other downtime possibilities.

Other Contingencies With Major Schedule Impact

1. The loss of any of three major test firing facilities for the main engine would have a major impact on schedules due to the rate of certification testing, R&D testing for new elements of the engine, and routine testing after maintenance and overhaul.
2. Unexpected rain damage to the thermal protection system.
3. A main shuttle engine (SSME) failure that damaged an adjacent engine or its controls.
4. Failure of gear to extend for landing.
5. A shuttle ditching.

LAUNCH RATE FINDINGS

In the 1990 time frame, the range of the number of annual STS flights, given a 4- and 5-Orbiter fleet, accounting for normal turnaround time, is estimated to be:

4-Orbiter fleet	17 to 25 flights per year
5-Orbiter fleet	22 to 31 flights per year

These estimates are based on fleets operating from both KSC and VAFB (one equivalent Orbiter) on a 5-workday week, 3-shifts-per-day basis (see Table II). A 5-workday week, which is in NASA's planning, wisely allows weekends to be used as buffers for schedule delays caused by normal problems attendant on any operational system.

In these estimates no attempt is made to account for contingencies such as anomaly- and failure-resolution delays, diverted landings, or accidents, which are realistic possibilities but cannot be quantified in any rational sense. These contingencies will reduce the maximum number of flights in unpredictable ways. However, in a positive vein, major configuration upgrades and major maintenance improvements may eventually reduce the downtime.

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IV

Capabilities Required to Support Various Launch Rates

Numerous capabilities of various types, some with a very high degree of complexity and sophistication, are needed to support the space shuttle. For the purpose of this study, capabilities are divided into three categories--operations, logistics, and major investment items--and their ability to meet launch rates of 18, 24, 30, and 40 per year is considered.

Operational functions discussed include launch and landing, flight, and training of flight crews and ground personnel. Launch and landing operations deal with the turnaround process and related facilities. The turnaround process is described in Chapter III and Appendix E.

The section on logistics includes a general discussion of space shuttle logistics support functions, along with the future role of the U.S. Air Force.

The section on major investment items covers the elements of hardware that make up the Space Transportation System--Orbiter, Space Shuttle Main Engine, Solid Rocket Boosters and Motors, and the External Tank--as well as payload preparation and integration.

The present chapter deals with the capability of these operational elements and supporting facilities to meet the prescribed launch rates.

OPERATIONS

Kennedy Space Center Launch and Landing Operations

The estimated launch rate capabilities of the major vehicle processing facilities at Kennedy Space Center (KSC) are shown in Figure 2. The upper dashed portion of the column represents the optimistic flight rate capability for each facility. The element with the largest uncertainty in potential is the Mobile Launch Platform (MLP). The MLP is in continual use from the time of mating the elements of the space shuttle upon it in the Vehicle Assembly Building, through launch and subsequent refurbishment. The projected reduction in MLP turnaround time is highly dependent on the effectiveness of planned improvements to the flight hardware. To reach a launch rate of 24 flights per year at KSC to support a total STS rate of 30 from both coasts, a fourth MLP may be required unless the MLP turnaround times can be reduced below those now projected. Similarly, for 32 to 34 flights per year from KSC, for a total of 40 from both coasts, a fifth MLP will be needed.

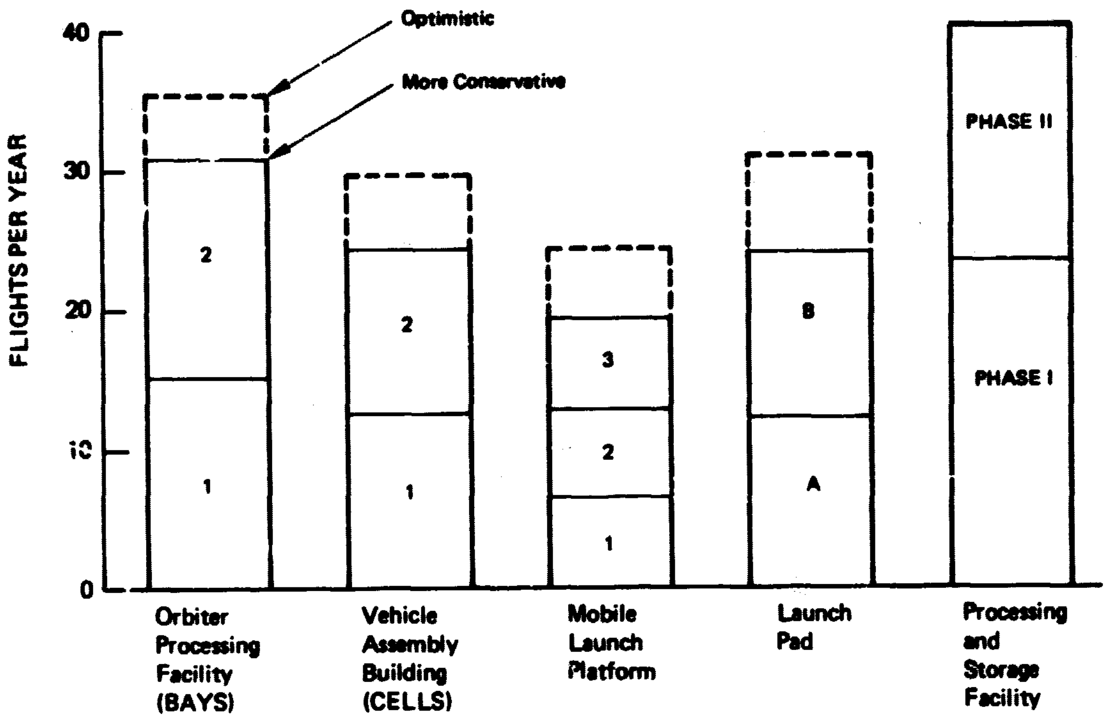

FIGURE 2 KSC Space Shuttle Turnaround Facilities

Should a fifth MLP be required, a third Vehicle Assembly Building (VAB) integration cell would be needed. The latter is believed to be a major facility demand that has not yet been adequately analyzed.

Other key launch facility requirements include (1) completion of Launch Pad B by January 1986 and (2) completion of a third firing room (FR-3) by October 1983, with the possible need for a fourth, FR-4.

The crosswind limitations of the Orbiter suggest that an additional runway should be considered at KSC to avoid diversions to other landing sites and an accompanying reduction in the total annual flight rate.

Flight Operations

Johnson Space Center is responsible for mission operations, planning and control, and development of the Orbiter. The Center's capability is limited by a number of factors. The Flight Control Room is a key element of the Mission Control Center in the preparation for and conduct of a given mission. Each flight has a unique set of support functions requiring control center reconfiguration. Such requirements include communications, launch performance indicators, software modifications (both internal to the Flight Control Room and to the Orbiter), flight control simulation and training, and a whole set of payload support activities, again unique to each mission. Supporting this activity and the flight preparation is a large mission planning and analysis function that requires considerable lead time for each flight, depending upon the complexity of the mission.

The USAF plan to utilize, in the near term, the NASA Control Center for secure DoD missions puts another constraint on the flight rate. An effort has been made to accommodate the DoD mission within the present NASA Mission Control facilities until the USAF plans to build a Shuttle Mission Control Center as part of the Consolidated Space Operations Center (CSOC) come to fruition. However, the timing for this control center addition, the scope of its facilities, and the continued budget restrictions that the USAF faces could put additional strain on the NASA Control Center. If the CSOC does become a fully operational facility in the later 1980s, it could relieve a pressure point in STS operations. NASA/DoD management attention is required now to prevent NASA Control Center facilities from becoming a limiting factor for the higher launch rates.

Careful attention has been required during the research and development phase of the STS to ensure reliable software performance. Although the existing software production computers are adequate to generate the on-board software that operates and drives the Orbiter, as flight rates build it will be a major challenge to provide the necessary software modifications and flight-to-flight changes. Further, software verification will necessitate continued vigilance to prevent hazardous errors from occurring. JSC has a number of plans formulated to handle the higher flight rate. With reasonable learning and a continuing effort toward simplification this should not be a limiting factor.

Training and Mission Control

There appear to be a sufficient number of candidates for astronauts and flight controllers to reach a rate of 40 flights per year. The training constraints to support this rate are facilities. These facilities include the Shuttle Mission Simulator, the Guidance and Navigation Simulator, Mission Control Center, the Water Immersion Facility, and "1-G mock-ups" of the Orbiter cabin. As indicated in Figure 3, a major limiting training element is the number of Shuttle Training Aircraft (STA). JSC currently has 2 STAs and approval for a third. This trainer is used for terminal-area and landing-approach flight training. The potential growth shown in Figure 3 is based on a reduction in the number of landings required for proficiency. The STA is a modified Gulfstream II. Because of its unique flight control system and aerodynamic shaping, great stress is placed on the airframe structure. The flight time requirements for crew training and the attendant lifetime restrictions on the aircraft make it a constraint. A fourth aircraft is seen as essential to support combined NASA and DoD requirements for 40 flights a year.

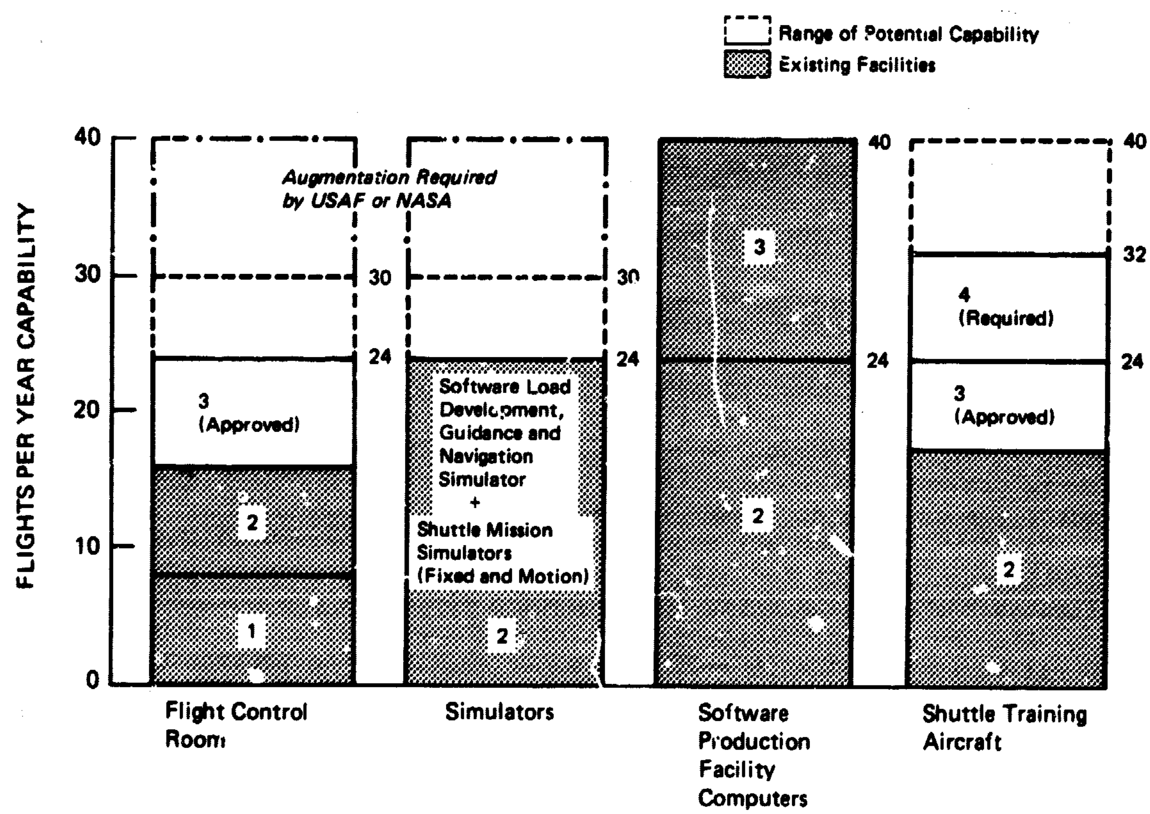

FIGURE 3 Training and Mission Control Capabilities (1989-1990)

Another constraining element is the Shuttle Mission Simulator, which NASA believes to be adequate for 24 to 30 flights per year. This equipment must be augmented by USAF or NASA facilities to achieve 40 flights per year. CSOC training facilities, if designed to support the unique DoD requirement for mission specialists, flight controller, and mission support personnel training may provide this augmentation (Figure 3). In any case the CSOC real time mission control facilities will be needed due to unique military requirements over and above STS control.

LOGISTICS

The term "logistics" is defined as the entire spectrum of activity required to support the buildup of the shuttle program to achieve increased launch rates and to maintain those rates over time. It includes, but is not limited to, planning, determination of requirements, budgeting, contractor selection, procurement, contract administration, acquisition, facility construction, spares provisioning, part storage and issue, modifications, refurbishment, maintenance, repair, disposal of excess material, and all related management information and communications. The NASA Centers share responsibilities for the total shuttle program, with extensive dependence on numerous contractors.

As the shuttle program has progressed, KSC has absorbed more overall responsibility in the logistics support area. Central to this is the future contract for a single Shuttle Processing Contractor (SPC), which is being competed by KSC. Recent overall NASA STS organizational changes have set a trend away from the traditional research and development type of operation toward an airline or weapon system support set of procedures designed to sustain flight operations.

Early budget contraints required that NASA give priority to meeting initial launch dates to the detriment of long-term operational considerations. The money apparently was not available for up-front procurement of an engineering database, reprocurement data, programming factors, sufficient spares, and overall management information. As a result, no coherent, long-range maintenance or spares provisioning plan has been instituted.

Only recently, senior NASA management recognized the philosophical change required. They have moved into place or recruited recognized experts in logistics to include those skilled in planning, acquisition, supply, maintenance, and repair. These individuals have done excellent work in preparing an initial foundation for what must follow. In addition, formal entree has been made to the USAF maintenance and supply support system. This in turn provides access to Navy, Army, and Defense Logistics Agency support activities.

In spite of the myriad of contractors involved, there seems to be no significant case in which NASA can invoke competition to improve costs. The result is a major dependence for replenishment or repair on former vendors who may have had to severely curtail operations or may be out of business, and on sole source procurement. In addition, as launch rates increase and Orbiter production winds down, the need for replacement parts will rise while production capacity diminishes or, indeed, disappears. Also, there are vehicle configuration differences and extensive variations between eastern and western launch site facilities.

The potential for logistics support problems exists. Although NASA has sought to be prudent in scheduling periodic inspection and maintenance at reasonable levels, it is difficult to predict what the proper rates should be. Earlier heavy maintenance may become necessary, or the first scheduled depot level inspection may disclose major repair requirements that cannot be put off for the rest of the Orbiter fleet.

In addition, the launch sites are exposed to environments where corrosion is severe. Even though STS post and preflight inspections are intense, the very nature of the equipment makes it difficult to be confident of inspecting all critical areas adequately. There is some potential for unscheduled requirements for large-scale replacement of parts or extensive repair.

The U.S. Air Force Role

The USAF role in the shuttle program is essentially that of a user. Through a traditional USAF System Program Office, its contributions are the construction of a western launch site facility at Vandenberg Air Force Base; development and production of an inertial upper stage to take payloads up to high geosynchronous orbit from a shuttle in low earth orbit, and DoD payload integration responsibilities. The latter includes construction of a Shuttle Payload Integration Facility at KSC/CCASF (Cape Canaveral Air Force Station).

The NASA/USAF effort to reduce rising vendor depot-level repair costs is assigned to the Sacramento Air Logistics Center of the Air Force Logistics Command (AFLC). The plan is to identify AFLC-wide depot industrial base capabilities that have potential as second repair sites, but the process is slow. It should be noted that the character of the shuttle program--few vehicles, unique hardware, and questionable continuity of the production base--represents a departure from the usual logistics center operation.

Need for Logistics Planning

In summary, while NASA has taken positive steps toward developing the kind of organization required to support planned launch rates, logistics difficulties may well pose serious obstacles to achieving those rates. These problems may manifest themselves not as a shortage of major investment items such as the ET or SRB, but rather as an inability to provide timely repair or replacement of parts needed to sustain launch site refurbishment and demanding Orbiter turnaround times. A coherent maintenance and spares plan has not been instituted. Many critical commodities are already subject to a diminishing manufacturing base, only waiting for crises to identify them. Unknowns in the results to be expected from launch site corrosion, vehicle stresses, and environmental extremes may cause serious delays to schedules. The number of flight articles is marginal for the lower launch rates and provides no backup for the higher launch rates. Cannibalization will not compensate for lack of spares at higher launch rates.

DoD depot repair support will increase but will be of limited overall assistance. Improvement will require management action to include better definition of individual NASA organizational logistics support reponsibilities, more direct access by senior NASA logisticians to top management, and hard budget decisions to promptly provide needed long-term support for the shuttle program.

MAJOR INVESTMENT ITEMS

Major investment items include the Orbiter itself with its maintenance and basic spares program, the Space Shuttle Main Engine, the Solid Rocket Booster and Motor, the External Tank, and payload preparation and integration. These items are discussed below with the exception of the External Tank and the specific questions regarding it that were posed to the Panel, which are dealt with separately in Chapter V.

Orbiter

Orbiter turnaround considerations are treated in Chapter III. Orbiter maintenance and reconfiguration activities are carried out in the Orbiter Processing Facility (OPF) which has 2 bays. Flight rates in excess of 30 per year will require the addition of a third. Orbiter maintenance and spares, and concerns regarding production stoppage, are discussed in the following sections.

Orbiter Maintenance Over the years, the airlines have learned that if an airplane fleet is to be continued safely in scheduled operation at high utilization rates for many years and many thousands of hours, a planned maintenance program must be developed.

If the Orbiter vehicles are each to be used for 100 or more missions, and future constraints on launch rates are to be minimized, a maintenance program needs to be thoughtfully developed at an early date. It should be designed to ensure that constraints do not develop in the future because of downtime required for safety modifications or caused by component, structural, or system failures and repairs. The best flight rates can be achieved if limited modifications can be incorporated at regularly scheduled downtimes.

As an example, major periodic maintenance and inspection of each Orbiter Vehicle (OV) is planned after 25 missions, with an estimated downtime of 5 months. Orbiter flights should be scheduled so that not more than one vehicle is down for service at any one time, with some leeway for unexpected downtime requirements.

There is concern that the 25-flight limit for major maintenance is arbitrary. While early experience with the first 5 flights was very good, it would appear wise to work up progressively to the 25-flight limit. This is the procedure developed by the airlines, with the concurrence of the FAA and the airframe manufacturers. While heavy maintenance services for widebodied jet transports in long use are currently set for about 25,000 hours, a new design transport is generally scheduled for heavy maintenance and inspection at less than 10,000 hours (9,000 for the B 747). If experience is satisfactory with the first few airplanes so inspected, the airlines extend the period in stages to 25,000 hours. The current layup of OV 102 and its planned layup next year should be used to accumulate and document such experience. It may be prudent as well to schedule a major inspection of another vehicle after approximately 15 flights.

In summary, if future constraints on launch rates because of maintenance requirements are to be avoided, a planned maintenance program should be developed promptly and carried into operation.

Basic Spares Program Because of the complexity of the R&D program itself, and the problems apparently imposed by budget ceilings, the spares programs and the planning of facilities for major maintenance of shuttle elements have lagged seriously. This situation exists for nearly all components and systems, as well as for instrumentation, test hardware, and ground equipment.

Concerns About Production Stoppage In assessing fleet capacity, the Panel became concerned with the ability to make major repairs or modifications during a period when the Orbiter production capability was not active. The ability to bring tooling out of storage, recertify it and the necessary personnel, acquire materials, fabricate, test, qualify, and deliver a major replacement such as a wing, while not technically in question, poses a potentially serious scheduling problem. For example, NASA and contractor estimates to repair/replace a wing are on the order of 6 months if the production base is in place and 36 months if it is not. The latter would clearly cause a severe setback in STS operations.

Space Shuttle Main Engine (SSME)

The SSME represents a major advance in rocket engine technology and its development continues to exhibit many problems. While the service record on the 5 flights of the OV 102 was excellent, serious difficulties were experienced with the next set of engines. The basic SSME program plan provides for 19 flight engines, 12 to be installed in Orbiters and 7 to be available as spares. However, current availability of spare pumps and engines appears critical and will remain so until well into 1984. NASA already has had to resort to parts cannibalization to meet test and operational schedules.

The present planned total of 19 engines appears barely adequate to support 24 missions per year, even assuming that removal rates do not become excessive. The 19 engines should be available by late 1985, whereas the 24-mission schedule does not commence until late 1987. If by 1987 the total removal rate exceeds 0.1 (1 removal per 10 engine cycles, 1 flight = 3 engine cycles), and the out-of-service time is not reduced materially, more spare engines will be needed.

Little background exists on which to base removal rate estimates, and therefore little is known about spares requirements. The removal of three engines from OV 099 implies a current removal rate of 0.4. A more thorough study of probable removal rates, planned service development of the engines and pumps, overhaul programs, etc., appears to be in order.

While the SSME service record on Columbia is encouraging, the plan to operate all 3 engines on OV 099 for 20 missions prior to removal for overhaul is less than conservative--especially in light of contemplated operation at higher thrust levels, and the fact that 10 successive simulated cycles at the higher thrust levels have yet to be achieved on the test stand, and there are no teardown inspection data that describe wear. It is suggested that engine removals from OV 099 be staggered, perhaps 1 at 10 cycles, and depending upon the engine's appearance, 1 at 15 and the third at 20. Such a sequence would:

1. Enable NASA to take advantage of the knowledge gained from earlier overhauls to define the life extension more accurately.
2. Decrease exposure to potential multiple failures since installed engines would not have the same age. Similarly, the probability of multiple deterioration of thrust, temperature control, and/or fuel consumption would be decreased.
3. Smooth out the flow through the engine overhaul shop, with beneficial effects on overhaul costs and spare engine availability.

Preliminary schedules for the planned engine overhaul program made available to the Panel show periods when no engines would be in the shop for as long as two years. This could result in the loss of experienced overhaul personnel and increased costs. With such a program it is questionable whether there would be sufficient reserve capacity for emergencies, such as multiple engine replacement.

The times scheduled for overhaul appear excessive. Engines from OV 102 are scheduled in overhaul for 18 months or more. Later engines are scheduled for slightly more than a year. Elimination of schedule gaps could favorably influence the time required for each individual overhaul. The present practice of shipping engines to California for overhaul and then to the National Space Technology Laboratories (NSTL) in Louisiana for tests will impede the availability of engines at higher flight rates. Consideration should eventually be given to locating an engine ground test facility at the launch site. The Panel recognizes this represents a major investment, however.

The high pressure fuel and oxidizer pumps appear more critical than the engine as a whole with respect to removal rates. Since these are replaceable with the engine in place on the Orbiter, sufficient additional spares should be available to support vehicle launch and projected pump unit removal rates. It is equally important that a coherent overhaul program be developed for these pumps.

There are indications that flight hardware spares are inadequate to support even current launch rates. These items include not only the pumps and turbines, but also the injectors.

A potential facility constraint associated with the SSME concerns test stands. There are three test stands, A-1 and A-2 at NSTL and A-3 at Santa Susanna, near Rocketdyne. The two at NSTL are used for normal testing and certification of engines as well as "green running" equipment such as liquid hydrogen and liquid oxygen pumps. Test stand A-3 is used in a similar fashion but also in development testing of modifications in hardware. It is an important adjunct to the other two and, at the current engine removal rate, should be kept in operation.

While qualification of the hardware to provide 109 percent of the full power level (FPL) is proceeding, much still needs to be accomplished. The high speed turbo machinery (high pressure fuel turbopump and high pressure oxygen turbopump) is limited to a range of 2000 to 3000 seconds of operation and will not achieve the life requirement of 55 flights per engine. Development problems still exist, for example, in turbine bearing and blade life. The "sub-synchronous whirl" phenomenon is not totally understood and this may restrict attempts to push the engine to higher performance in the future. The full-scale main propulsion test requiring 3 engines firing at full power is a milestone to be achieved and presents a challenge to shuttle management.

History has shown that hardware is often consumed during test programs and, in this respect, the hardware limits of the present production scheme may well represent a constraint. Finally, the Panel emphasizes the newness of the technologies and operations involving the main engines and recognizes that development of this portion of the STS must continue beyond most other components. It may be of interest to note that historically, air transport engine manufacturers have budgeted half of their development costs to be applied after an engine is put into service.

Solid Rocket Booster (SRB)

The SRB has yet to reach the production and refurbishment rate necessary for 18 flights a year.

SRB Refurbishment and Assembly The retrieval, disassembly, refurbishment, and reassembly of the Solid Rocket Booster (SRB) structural subsystems (exclusive of the Solid Rocket Motor cases) is performed at KSC and the Cape Canaveral Air Force Station (CCAFS). Appendix F shows stages of SRB refurbishment. This activity currently takes place in the following facilities:

Retrieval	Two recovery ships
Disassembly	Hangar AF (CCAFS)
Parachute facility	KSC industrial area

Refurbishment	Hangars AF & N and the VAB
Assembly and storage	VAB and planned PSF (Processing and Storage Facility)

Because of the limited experience from the first 6 launches, there is considerable uncertainty as to the eventual launch rates that the current tooling, processes, and facilities will support. Overall, the refurbishment task is significantly greater than originally planned because the aft structure (skirt), thrust vector control actuators, and auxiliary power units have experienced more extensive water impact damage than expected. Several design modifications have already been incorporated to improve this situation, and others are planned.

The following is a list of concerns and future requirements according to Marshall Space Flight Center, United Space Boosters, Inc. (USBI) and Thiokol representatives:

1. A new $9 million, large-area building at the Solid Rocket Motor contractors' facility is needed to allow rocket segments to be poured without interruption by inclement weather.

2. Current ad hoc arrangements at KSC will not support increased flight rates. A new refurbishment facility is necessary to disassemble, clean, repair and reassemble the forward and aft skirt portions of the SRB. USBI has proposed to finance and build at Cape Canaveral such a facility with a planned 24-per-year flight rate--with potential for expansion. NASA currently has under study several alternative facility concepts. These include consolidating the disassembly and refurbishment activities into new or expanded facilities at or near KSC. Transferring the operation to Marshall Space Flight Center is also under consideration. Planning and budgets support flight rates up to only 16 per year in the present refurbishment and production facilities. The tooling and facility planning for rates of 24 per year with expansion capacity up to 40 is underway. These facilities must be in place and sufficient spares on hand by mid-1987 to support 24 flights per year in 1988.

3. The recovery operation is a formidable one but has operated effectively to date, with the exception of a parachute mechanism failure.

4. Reuse of rocket cases and other hardware is essential to meet the schedule. However, sufficient spares must be available in the event of losses or extensive damage. The long-term effects of corrosion and erosion have not been fully assessed.

5. Aft skirts are in short supply, and current refurbishment and production rates will not meet the 24-per-year launch rate. The extent to which the aft skirts are damaged upon recovery suggests more of these items are needed.

6. The filament wound case being developed for use on special performance missions appears to be on schedule. However, the mixed inventory of metal and filament wound casings may require stockpiling extra segments to achieve logistic integrity.

In summary, the Panel found reason to doubt that the existing SRB facilities would be able to support flight rates above 16 per year. Both NASA and the contractor are acutely aware of the uncertainties and over the past year have assessed more than 10 options. The specific configuration of refurbishment and production facilities is expected to be agreed upon in 1983.

Refurbishment of Motor Only (SRM) The SRM is the largest Solid Rocket Motor ever flown and the first designed for reuse. Solid Rocket Motor case refurbishment and recasting is performed within contractor-owned facilities. The planning and budgeting is in place for both contractor- and NASA-provided equipment for reaching a rate capability of 24 flights per year. Implementation will be completed in 1987. For rates above this level the tooling and facilities requirements have been identified and, in keeping with the past practice wherein the contractor capitalizes nonseverable tooling and facilities and NASA funds severable tooling, the budget estimates have been formulated.

However, the SRM segments are transported by rail to and from Utah for refurbishment and recasting. If the assumed 7 days in transit each way for propellant segments is exceeded, additional segments and spares will be required in the system.

Another potential constraint to SRM production above 24 flights per year may rest not with the SRM prime contractor but with the suppliers of ammonium perchlorate. Currently, the production of this major propellant ingredient is being expanded by the only two suppliers in the nation to meet the expected demand in the near future. If a rate above 24 flights per year is sought, either a new plant or further expansion will be required. Hence ammonium perchlorate could constrain the STS until there is capitalization for higher production.

Payload Preparation and Integration

The operational phase of the STS introduces a host of new factors in preparing and integrating the payloads, or cargo, to be transported into space. Varied payloads, multiple customers (some with limited space experience), coping with late changes, the need for safety and security, and the requirement for quicker processing and operational efficiency all combine to present the STS managers with substantial challenges.

The customers who will fund and provide payloads for STS include NASA, DoD, and commercial enterprises (both domestic and foreign). Priorities for assignment are as follows:

- NASA security missions for DoD
- Major NASA science missions (e.g., space telescope)
- Commercial missions (domestic and foreign treated equally)
- Other U.S. government missions

NASA Headquarters is responsible for establishing policies relating to payload preparation and integration and for negotiating launch service agreements with customers. JSC is responsible for flight safety and for the technical interface with customers leading to publication of the payload integration plan. KSC is responsible for the ground safety of the payloads from their arrival at KSC until they are launched on the Orbiter.

The STS provides an environment that is substantially more benign than that of the expendable launch vehicles. However, increased interface complexity results from mixed payloads, the safety requirements necessary for a manned vehicle, and the security needs of DoD.

This complexity will be eased as the STS is better defined and understood and in time should be offset by the increased reliability of the shuttle.

Payload processing at KSC is now done by NASA and the Air Force in government facilities. These facilities are inadequate to handle the throughput and if not substantially augmented will present a major limitation to annual flight rates. For example, only one of the two cells in the Vertical Processing Facility is fully operational. Full utilization of the second cell would be needed to reach a flight rate of 24 per year.

In anticipation of a rapidly increasing requirement for payload processing, NASA has programmed funds to improve existing facilities and has plans to add new ones. It is imperative that this construction program continue at the scheduled pace. Further, the adequacy of this effort should be reevaluated as operational experience is gained.

In addition to the planned enhancement of NASA payload processing facilities, two commercial contractors are exploring privately-owned facilities for this purpose. The Panel assumes the Air Force will continue to process DoD payloads both at KSC and Vandenberg AFB and will supply the facilities to maintain the flight rate.

Once the payloads are processed for launch at KSC they are transported in a payload canister transporter. At present, there is only one such vehicle but a necessary second is planned. Payloads can be inserted into the Orbiter payload bay either horizontally while the Orbiter is in the Orbiter Processing Facility or vertically after the Orbiter is on the launch pad.

In addition to the problems discussed above, particular attention should be given to the length of time required for processing, for handling hazardous cargo, and for coping with payload changes.

At present, 4 months are allowed for payload processing after arrival at KSC. NASA should work vigorously toward the planned reduction of this time to 2 months and preferably less. Present NASA mission planning documents show it could take as long as 9 months to cope with a significant change in mission payload. This inflexibility is undesirable, and stringent efforts by NASA are needed to meet or better the planned goal of a 3-month maximum.

In summary, planning for payload processing and integration for the operational STS is demanding. However, NASA, Air Force, and industry have all devoted considerable time and effort to this matter, and approved programs, if funded and completed on schedule, should provide adequate capability. Care should be taken in the provision of facilities and ground equipment to prevent payload preparation and integration from becoming a limiting factor at the higher shuttle flight rates now under consideration.

V

External Tank Production

The expendable External Tank (ET) is the component of the space shuttle that supplies propellants to the Orbiter's main engines. It is produced for NASA at the Michoud Assembly Facility (MAF) under contract with Martin Marietta Aerospace Co. The current production rate is 13 tanks per year, with the probable capability of 18 per year. Plans have been made for facilities and tooling to meet a production rate of 24 tanks per year by 1987 and for eventual expansion to rates of 30 and then 40 per year.

FACILITY CONFIGURATION

External Tank production is undertaken in one large main manufacturing facility--the 43-acre Building 103--and several smaller facilities, all of which were in existence and served prior uses at Michoud. Existing on-site reinforced foundations in Building 103 were used for the heavy assembly and welding tools. Because of the need to increase production rates and streamline the flow of tanks through the plant, it is necessary to relocate some of the large major tools and to transfer some of the thermal protection system (TPS) activities to a new, auxiliary site.

This major new facility, costing $15 million, is presently being prepared and will remove the application of the super light ablator (SLA) from the main building. This will provide added space in Building 103 for application of the other type of thermal protection, a low density spray-on foam insulation (SOFI) at an accelerated rate.* The move will also help avoid contamination from the silicone

*The SLA is bonded to certain local areas of the External Tank for protection against high heating in regions of its interface with the Orbiter and SRBs and from engine exhaust. The SOFI is sprayed over the entire external surface of the tank primarily to prevent ice formation due to the low temperature of its liquid oxygen and liquid hydrogen contents.

used in manufacturing the SLA and will help control the environmental conditions for application of the SOFI. The building is being designed to accommodate future expansion for rates above 24 per year. It appears that sufficient space is available within Building 103 to sustain an eventual assembly of 40 tanks per year.

Table III and Figure 4 include estimates of additional facility and tooling requirements with associated costs for production rates of 24, 30, and 40 tanks per year along with the projected dates of availability for these rates. No major changes in facility concept or manufacturing processes are anticipated for rates above 24 per year. Modifications to existing facilities (Table III and Figure 4) will be required, along with major investment in tooling (Table III). The budget additions (Table III) for the planned rate of 24 per year will appear in the fiscal years 1984 through 1987.

IMPACT OF INCREMENTAL PRODUCTION INCREASES

There appears to be no major advantage in immediately funding facilities and tools for a flight rate of 40 per year. As shown on Table III, an increase in production from 24 per year to 30 per year and finally 40 per year involves only progressive improvements to the facilities.

In addition to delaying the financial outlay by proceeding in stages, benefits may be gained by (1) the effects on future manufacturing processes of on-going learning experiences, and (2) a potentially significant adaptation of robotics to Michoud ET production.

FINDINGS

To date there has been good ET production experience, and schedules are being met; vendors are in place for 24-per-year capability and higher as required; the tooling and facilities needed to reach various production rates are understood. The Panel could discern no major constraints to producing quality tanks at rates of 24, 30, or 40 per year if resources are provided to allow for proper lead times in tooling, material, and plant accommodations. The only reservation expressed by the Panel members concerned transportation to the launch site, particularly the plan to ship two tanks per barge to the West Coast via the Panama Canal. A degree of stockpiling at Vandenberg was recommended to avoid a deterrent to launch on demand.

TABLE III Requirements for External Tank Production and Availability for Various Production Rates (Real Year $)

	Investment to Date	24/Yr. (6 tanks/quarter) In 1984 Budget	24/Yr. (6 tanks/quarter) Additional	30/Yr. (8 tanks/quarter)	40/Yr. (10 tanks/quarter)
Facility Requirements		Mods. to production flow X-Ray, Mod. and staging facility SOFI component facility mod. Tank Farm Phase II	Contingency proof test facility Completion of barge dock modifications Improvements to cleaning facilities	2 additional TPS cells (cells R & S) Third checkout cell Expansion of TPS component area Plant layout improvements including removal of mezzanine	Additional TPS cell (cell L) Expansion of the ET staging facilities TPS component Demineralized water tank farm Phase III
	$82 M*	+$25-$30 M		+$55 M	+$30 M
Tooling	$275 M	+$175 M		+$90 M	+$70 M
Total	$357 M	+$200-$205 M		+$145 M	+$100 M
Date of Availability		Mid-1987		Early 1989	Early 1991

*Includes Component Ablator Facility.

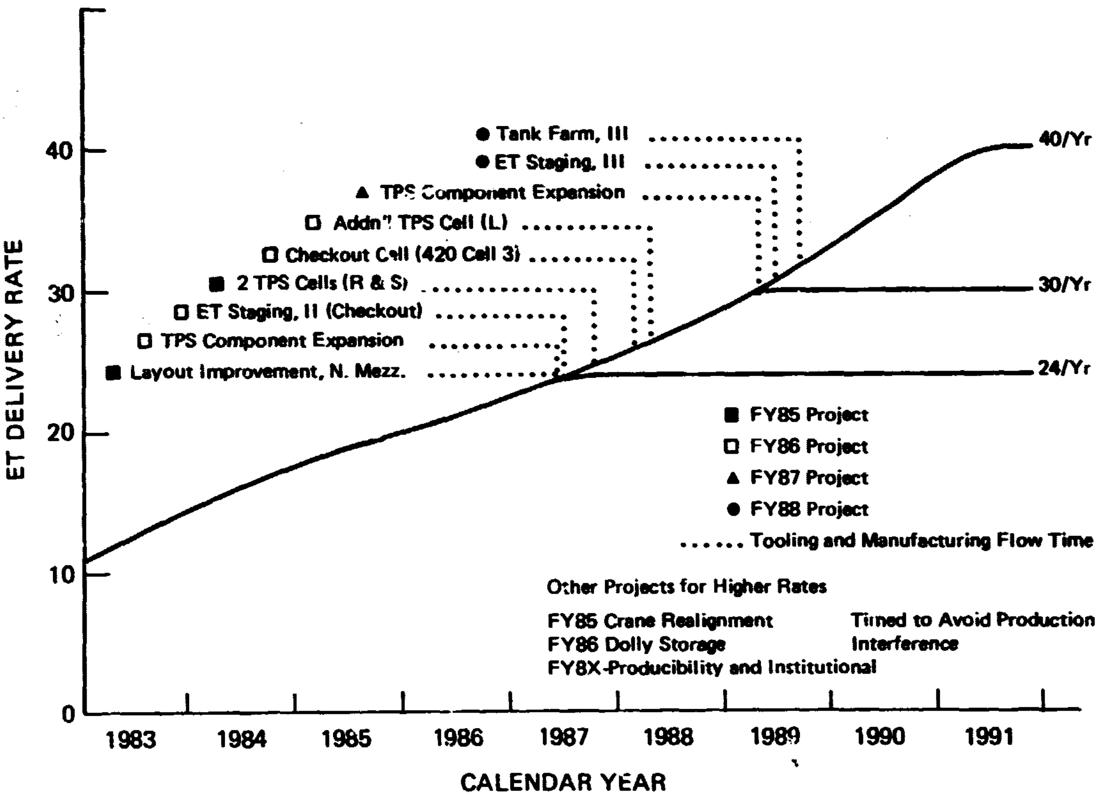

FIGURE 4 Major Facilities Requirements to Support Higher ET Build Rates (Courtesy of Martin Marietta, Michoud Division)

VI

Summary and Conclusions

In assessing the constraints on space shuttle launch rates, the Panel considered separately the components of the space shuttle and the potential capabilities to meet various flight rates, as well as the supporting facilities and services. In addition to these capabilities, major contingencies were considered (Chapter III). Such major contingencies cannot be quantified, and it must be understood that the following estimates of STS capabilities will be reduced by any such occurrence.

LAUNCH RATES

The basis for estimates of launch rates, hardware requirements, and other capabilities is limited because there is little experience in space shuttle turnaround, no experience regarding major Orbiter maintenance, and the operations at Vandenberg are still in the planning stages. Thus, as discussed in preceding chapters, the following assumptions were made in providing the Panel's assessments: (1) the equivalent of one Orbiter is dedicated to VAFB-launched missions, (2) no contingencies occur that would take an Orbiter out of service beyond the 5 months for maintenance scheduled after every 15 (conservative estimate) to 25 (optimistic estimate) missions, (3) mission duration averages 5 to 7 days, and (4) work is accomplished on a 5-workday/3-shift schedule, allowing weekends to recover from schedule delays. Based on the above assumptions, the broad range of the number of annual STS flights in the 1990 timeframe is estimated to be <u>17 to 25 flights per year for a 4-Orbiter fleet</u> and <u>22 to 31 for a 5-Orbiter fleet</u>.

CAPABILITIES OF MAJOR STS COMPONENTS

The capabilities of components of the space shuttle to meet various launch rates are shown in Figure 5.

Annual Launch Rate	Orbiter Fleet Size 4	Orbiter Fleet Size 5	Orbiter Fleet Size 6	Space Shuttle Main Engine	Solid Rocket Booster	External Tank
18	OK	OK	OK	OK	M[1]	OK
24	M	OK	OK	M[1]	X[2]	OK
30	X	M	OK	X	X	OK[3]
36	X	X	M	X	X	OK[3]
40	X	X	X	X	X	OK[3]

M = marginal
X = impossible or highly improbable
[1] with existing production/refurbishment facilities
[2] options for SRB being studied
[3] firm plans exist to meet increased production requirements
*Longer missions and/or major mishaps decrease the potential number of yearly launches

FIGURE 5 Capabilities of STS Components to Meet Various Launch Rates
5- to 7-Day Mission Duration

Several conclusions may be drawn from this figure:

1. For the 24 missions per year now planned, a minimum of 4 Orbiters is essential. In the event of extended mission duration, more frequent repair, longer overhaul periods, or contingencies that incapacitate an Orbiter for a prolonged period, the number of yearly launches may be reduced significantly below 24.

2. The <u>External Tank</u> appears to be the only major component of the STS for which firm planning is in place to attain levels of 24, 30, and 40 flights per year. As discussed in Chapter V, no major

technology advances or changes in production procedures are required to provide quality tanks at the required launch rates. The Panel has no reason to believe that the schedules cannot be met.

3. Solid Rocket Booster requirements must be derived from experience, but estimates indicate that a minimum of 24 aft skirts would be required for sustaining 24 flights per year (20 are now planned), and 40 will be needed for 40 flights per year. Neither quantity allows for attrition. Similar increases in forward skirts and aft propulsion segments should be expected.

The planning is not in place and procedures remain to be developed to refurbish Solid Rocket Boosters to meet the mission model. In addition, because of the extent to which the aft and forward skirts of the SRB may be damaged in recovery from the ocean, the mixed inventory of metal and filament wound casings, and the lack of experience regarding life expectancy of many SRB parts, the Panel encourages a heavy spares policy.

Refurbishment and recasting of the Solid Rocket Motor segments by the contractor appeared from the briefings the Panel received to be proceeding without significant problems.

4. Space Shuttle Main Engine quantities now planned for operations and spares--19 in all--are considered marginal to support 24 flights per year. Even this rate will not be reached unless major spares programs are instigated, particularly for the high pressure liquid hydrogen and liquid oxygen turbopumps. The Panel anticipates the SSME will continue under development for many years and that the above turbopumps may have to be redesigned for longer life.

FACILITIES SUPPORTING FLIGHT OPERATIONS

The development of the STS to an efficient system requires controlled expansion of its support facilities to achieve increased launch rates in a cost-effective way. Figure 6 presents a summary of the facility requirements, discussed in Chapter IV, as a function of the yearly shuttle launch rate for 11 major STS operational facilities. The estimates are based on the best judgment of the Panel members in light of past experience and information received from NASA and relevant contractors.

The existing and already-funded facilities will now accommodate about 18 launches per year, but to reach 24 launches some additions are required--Mobile Launch Platform, Processing and Storage Facility, and Vertical Processing Facility. To achieve 30 launches per year, significant additions are required for most of the 11 facilities, and all need additions to reach the 40 per year launch rate. It should be noted that many of the facility requirements are directly dependent upon the STS turnaround time.

	Ground Turnaround					Cargo	SRB Refurb.	Flight Training		Flight Opns.	
Annual Launch Rate	Orbiter Processing Facility	Vehicle Assembly Building	Mobile Launch Platform	Launch Pad	Firing Room	Vertical Processing Facility	Processing and Storage Facility	Shuttle Mission Simulator	Shuttle Training Aircraft	Flight Control Room	Shuttle Carrier Aircraft
18	2	2	2	2	2	1½[b]	1	2	2[d]	2	1[d]
24 (4-5)*	2	2	3[a]	2	2	2	1	2	3	2	2
30 (6)	2	2	3-4[a]	2	3	2	2	3[c]	3+	3	2
40 (6-8)	3†	3	5[a]	3	3-4	3	2	3[c]	4	3	2

*Assumed launches from Vandenberg AFB
†Circle indicates additional requirement
[a]KSC requirement only
[b]Second bay not completely functional
[c]Includes support to USAF
[d]Does not allow for aircraft loss or disablement

FIGURE 6 Capabilities Supporting STS Operations (Cells or Units).

LOGISTICS, MAINTENANCE AND SPARES

The STS has done remarkably well on its first 5 flights, and since the long-term spares and maintenance program requirements should be based on experience, it is not surprising that a coherent spares and maintenance program is just developing. Operation of the STS in an efficient and routine manner demands that strong emphasis be placed on providing adequate spares and on a systematic maintenance and logistics policy. Inevitably, such a program must address the need for retaining elements of the Orbiter production line to permit reasonable replacement of all key component parts as required. This is particularly critical for the production of very long lead time elements of the Orbiter structure and systems.

The Panel reemphasizes that the complexity of the STS systems, the R&D nature of present flight experience, and the mixed status of the supplier base all demand that experienced attention be given to developing the logistics of the system, to making sound estimates of maintenance needs, and to developing an adequate spares program. Budget limitations and R&D pressures have suppressed the development of these support programs in the past. This leads the Panel to suggest that the most prominent constraints to launch rates in the early growth of the STS as an operational system may manifest themselves not as a shortage of major investment items such as the ET or SRB, but rather as an inability to provide timely repair or replacement of flight system components needed to sustain launch rates.

CONCLUDING REMARKS

The first 6 flights of the space shuttle were successful and stand as a credit to NASA and the national effort behind it.

Because of very strict budgetary constraints in the space shuttle program NASA has had to concentrate on the near-term needs, and its capacity to deal with the longer-term requirements was inevitably curtailed.

Of particular concern to the Panel are the implications of a shutdown of STS production and the attendant loss of skills, tooling, and contract manufacturing capabilities in general. Reinitiation of STS production lines at a later date becomes a formidable task. Not only will costs be higher but production lead times will be considerably longer--e.g., the lead time for an Orbiter wing increases from 6 to 36 months--and there may be a need to requalify a high percentage of the STS systems.

The success of the space shuttle's operational future is dependent on its cost effectiveness and on the timely availability and proper functioning of an extensive and complex array of facilities, components, and services requiring long-term planning.

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Appendixes

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Appendix A

LETTER DATED OCTOBER 27, 1982, FROM THE HONORABLE EDWARD P. BOLAND, U.S. HOUSE OF REPRESENTATIVES, AND THE HONORABLE JAKE GARN, U.S. SENATE

United States Senate
COMMITTEE ON APPROPRIATIONS
WASHINGTON, D.C. 20510

October 27, 1982

Mr. James M. Beggs
Administrator
National Aeronautics and Space
Administration
Washington, D.C. 20546

Dear Mr. Beggs:

We are writing in response to your September 13, 1982 request to reprogram $15 million of FY 82 R&D funds for the purpose of building a new super light ablator (SLA) facility at Michoud and modifying the existing SLA facility. The Appropriations Committees are interested in examining additional production options in order to assure the availability of external tanks to meet realistic shuttle flight rate requirements. As you are well aware, this is an issue of considerable national importance which may affect U.S. capabilities in space for the next decade and beyond.

As we have done in the past, we would like to request that NASA call upon the National Research Council (NRC), Committee on NASA Program Reviews, to examine the implications of this proposed action.

Specifically, we request that the following information be provided by the NRC:

1. An estimate of the range of the number of annual STS flights, given a four- and five-orbiter fleet, accounting for normal turn around time and contingencies.

2. An overview of the capabilities needed to support these estimated flight rates including rates of 18, 24, 30 and 40 a year with a survey of known constraints or limiting factors.

3. An estimate of the facility modifications and requirements needed to match production of external tanks to the above annual shuttle flight rates, including consideration of learning curve effects.

4. An estimate, based on available data, of the costs associated with the external tank facility modifications including any additional costs that might be incurred by modifying the facility to first support 24 flights a year and then later increasing the capability to support a higher flight rate.

5. An estimate of the date that external tank production would be available to support each of the flight rates determined above.

We would appreciate your cooperation in forwarding this request and in assisting with the study. A report covering these issues should be available to the House and Senate Appropriations Committees by April 22, 1983.

Sincerely,

Edward P. Boland
Chairman
House Subcommittee on HUD-Independent Agencies

Jake Garn
Chairman
Senate Subcommittee on HUD-Independent Agencies

cc: Dr. Frank Press

Appendix B

COMMITTEE ON NASA SCIENTIFIC AND TECHNOLOGICAL PROGRAM REVIEWS

NORMAN HACKERMAN, President, Rice University, Houston, Texas, Chairman

WILLIAM A. ANDERS, Vice President and General Manager, General Electric Company, Dewitt, New York

RAYMOND L. BISPLINGHOFF, Director for Research and Development, Tyco Laboratories, Inc., Exeter, New Hampshire

EUGENE E. COVERT, Professor of Aeronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts

ALEXANDER H. FLAX, President, Institute for Defense Analyses, Alexandria, Virginia

RICCARDO GIACCONI, Director, Space Telescope Science Institute, Johns Hopkins University, Baltimore, Maryland

JOHN W. TOWNSEND, Jr., President, Fairchild Space Company, Germantown, Maryland

HERBERT FRIEDMAN, CoChairman, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, Washington D.C., Ex-Officio Member

H. GUYFORD STEVER, Chairman, Commission on Engineering and Technical Systems, National Research Council, Washington, D.C., Ex-Officio Member

ROBERT H. KORKEGI, Executive Director

JOANN CLAYTON, Staff Officer

ANNA L. FARRAR, Administrative Assistant

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Appendix C

STATEMENT OF TASK
AN ASSESSMENT OF CONSTRAINTS ON SPACE SHUTTLE LAUNCH RATES WITH EMPHASIS ON EXTERNAL TANK PRODUCTION

The National Academy of Sciences/National Academy of Engineering through the National Research Council contracted to furnish the National Aeronautics and Space Administration, through the NASA Chief Engineer, an assessment of Constraints on Space Shuttle Launch Rates with Emphasis on External Tank Production in response to Congressional request. This study is the third task under a broader contractual arrangement with NASA to provide Congress with NRC reviews of proposed changes in NASA programs. The request issued by letter dated October 27, 1982, from Senator Garn and Congressman Boland to NASA Administrator James Beggs asked for the following information which constitutes the charge, with a report to be available to the House and Senate Appropriations Committees by April 22, 1983:

1. An estimate of the range of the number of annual STS flights, given a four- and five-orbiter fleet, accounting for normal turn around time and contingencies.

2. An overview of the capabilities needed to support these estimated flight rates including rates of 18, 24, 30 and 40 a year with a survey of known constraints or limiting factors.

3. An estimate of the facility modifications and equirements needed to match production of external tanks to the above annual shuttle flight rates, including consideration of learning curve effects.

4. An estimate, based on available data, of the costs associated with the external tank facility modifications including any additional costs that might be incurred by modifying the facility to first support 24 flights a year and then later increasing the capability to support a higher flight rate.

5. An estimate of the date that external tank production would be available to support each of the flight rates determined above.

To deal with the request for carrying out reviews of NASA programs, the NRC established the Committee on NASA Scientific and Technological Program Reviews. In order to address diverse problems, the Committee has been authorized to establish <u>ad hoc</u> review panels, of which this--the panel to assess constraints on space shuttle launch rates--is the third.

In carrying out this assessment, account should be taken of recent NRC studies associated with component and operational aspects of the space shuttle.

In regard to the charge, the panel is asked to:

1. Consider throughout only a four- and five-orbiter fleet, taking into account orbiter availability dates, turnaround, maintenance and refurbishment requirements.

2. With respect to paragraphs 2 and 3 of the charge use as a maximum launch rate per year the answer to paragraph 1 of the charge; if it is 32, then use launch rates of 18, 24, and 32 in response to paragraph 2 in lieu of the 18, 24, 30, and 40 indicated; if it is 36, then use 18, 24, 30, and 36.

3. Address elements of the Space Transportation System including payload handling and integration, but excluding payload availability.

4. Provide an overview of capabilities and constraints based upon available data, including the relation of external tank production to shuttle launch rates.

5. Consider tooling and other R&D expenditures as well as facility requirements in responding to paragraphs 3 and 4 of the charge.

It is expected that on-site visits to both the external tank production facilities and the space shuttle launch area will be necessary.

It is understood that NASA will provide information and data on program plans, production, operations, schedules and costs associated with space shuttle components and launch rates.

It is requested that the task be completed and the report be forwarded to the Committee on NASA Scientific and Technological Program Reviews by April 7, 1983.

Committee on NASA Scientific and Technological Program Reviews
Washington, D.C.
November 18, 1982

Appendix D

NASA/CONTRACTOR PARTICIPANTS IN BRIEFING SESSIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HEADQUARTERS

L. MICHAEL WEEKS, Deputy Associate Administrator (Technical), Office of Space Flight
JERRY J. FITTS, Director, SRB and External Tank Division*
CHARLES R. GUNN, Deputy Director, Space Shuttle Operations Office
RUSSELL BARDOS, Integrated Logistics
CHARLES H. NEUBAUER, Program Manager, Facilities
RICHARD T. SCHUBERT, Special Assistant (Logistics)
DAVID L. WINTERHALTER, External Tank, Propulsion Division

JOHNSON SPACE CENTER (JSC)

WILLIAM J. BONEFAS, Chief, Orbiter Logistics Office
DONALD T. GREGORY, Manager, Integrated Logistics
GLYNN S. LUNNEY, Manager, Space Shuttle Program

KENNEDY SPACE CENTER (KSC)

RICHARD SMITH, Director, KSC
GEORGE PAGE, Deputy Director, KSC
GEORGE ENGLISH, Director, Executive Management Office
WILLIAM ROCK, Director, Shuttle Projects Office
SAM BETTINGFIELD, Chief, Program Assessment and Integration Staff
JOHN NEILON, Manager, Cargo Projects Office
GREGORY A. OPRESKO, Logistic Management Office
HENRY PAUL, Deputy, Design Engineering
WAYNE STALLARD, Manager, Manifest/GPS
BOB YARBOROUGH, Chief, Cargo Facilities and GSE Program Office

*New Assignment--Deputy Director, Customer Services

MARSHALL SPACE FLIGHT CENTER (MSFC)

WILLIAM R. LUCAS, Director, MSFC
VINCENT P. CARUSO, Chief, SRB Production Management Office
JOHN W. HARDEN, Resident Manager at KSC
JUDSON A. LOVINGOOD, Manager, SSME Project
LAWRENCE B. MULLOY, Manager, Solid Rocket Booster Project
JOHN A. NEWTON, ET Project
JAMES B. ODOM, Deputy Manager for Production and Logistics, Shuttle Projects Office

MICHOUD ASSEMBLY FACILITY

NASA

JOHN W. HILL, ET Resident Manager
M. SIEBEL, Manager, Michoud Assembly Facility

Martin Marietta

K. P. TIMMONS, Vice President and General Manager, Michoud Division
R. M. DAVIS, Vice President for ET Project and Deputy General Manager
A. M. NORTON, Vice President-Development
C. O. BEASLEY, Manager, Planning and Control
I. M. GUILLORY, Staff Member, Planning and Control
E. F. HOOKS, Staff Member, Planning and Control
GAYLE HOWELL, Manager of Production Engineering
K. H. SEANER, Secretary, Planning and Control

THIOKOL

JOE C. KILMINSTER, Deputy Director, SRM Project
JACK BUCHANAN, Manager, THIOKOL KSC Operations
WALTER JOHNSON, Manager, SRM Manufacturing Engineering
JOHN R. WELLS, Manager, THIOKOL Manufacturing Engineering

UNITED SPACE BOOSTERS, INC.

FRANK LAVACOT, Executive Vice President
BERNARD COCCHI, Vice President-Operations
PAUL DONNELLY, Vice President-Florida Operations
B. FRANKLIN, Florida Facilities Manager
A. GUTHRIE, Industrial Engineering Staff
T. OTT, Manager, Manufacturing Operations
GEORGE ROSENHAUER, Florida Program Manager

Appendix E

SHUTTLE TURNAROUND OPERATIONS

Prepared by the NASA Office of Space Shuttle Operations for the NRC Panel to Assess Constraints on Space Shuttle Launch Rates.

Shuttle turnaround operations are paced by the Orbiter processing through the critical path. The Orbiter critical path extends from landing at the Shuttle Landing Facility (SLF), through tow to the Orbiter Processing Facility (OPF) for processing as a flight element, rollover to the Vehicle Assembly Building (VAB) for assembly with the Solid Rocket Boosters (SRBs) and External Tank (ET) on the Mobile Launch Platform (MLP) and subsequent shuttle vehicle rollout to the pad for servicing, checkout and launch. The principal parallel activities include stacking the two SRBs on the MLP and mating the ET to the SRBs while the Orbiter is being processed in the OPF.

LANDING

After Orbiter landing at the SLF, safety checks for venting gasses are made, environmental purge and coolant ground-services are connected. The flight crew egresses and a ground crew ingresses. A tow tractor is connected and the Orbiter is towed to the OPF, with ground-service umbilicals connected.

OPF

In the OPF, the Orbiter is jacked and leveled, access platforms are positioned, and purge air, coolant, power and other ground services are connected. After safing the ordnance, hypergolic propellants and other systems, the maintenance and reconfiguration activities are initiated. Orbiter maintenance includes inspection and repair or replacement of any failed components, including thermal protection system (TPS) tiles.

Space Shuttle Main Engine (SSME) maintenance includes inspections and leak checks every mission, turbine torque tests every third mission (or one engine each mission), and component and engine replacements on a less frequent schedule. Also the Orbital maneuvering system (OMS) pods and forward reaction control system (FRCS) module are removed and/or exchanged every fifth mission and taken to the

Hypergolic Maintenance Facility (HMF) for a detailed inspection, test and servicing in parallel with other Orbiter work in the OPF. The payload, payload support fittings, and mission kits from the previous mission are removed and those for the next mission are installed. For payloads that are to be installed vertically at the Pad, support fitting and mission kits are pre-installed in the OPF at this time. The Orbiter integrated test is performed to verify the functional integration of Orbiter and payload systems. The access and ground-service connnections are removed and the Orbiter is towed to the VAB for mating.

PARALLEL OPERATIONS FOR SRB AND ET

After the solid propellant is expended in launch, the SRB's are jettisoned from the space shuttle, and descend to the sea by parachute. They are retrieved and towed to shore by special recovery ships. When on shore they are cleaned and disassembled, and the eight motor segments are returned to Thiokol's Utah facility for reloading of propellant. Damage to the aft and forward skirt assemblies caused by reentry and impact with the water is repaired, and the skirt assemblies, thrust vector control actuators and auxiliary power units are refurbished. Such repairs and refurbishments are presently conducted in Hangars AF and N and in the low bay area of the VAB at KSC.

While the Orbiter is being processed in the OPF, the SRBs and ET are processed and assembled in the VAB to be ready for Orbiter mate. The four motor segments per SRB arrive horizontally on railcars and are off-loaded, rotated and stored vertically. The SRB aft booster assembly buildup includes mating the aft segment onto the aft skirt assembly and attaching the nozzle extension to the aft segment nozzle assembly. The segments are then lifted individually by crane to the VAB and stacked on the MLP, which is located in one of the two assembly cells in the VAB. The two aft booster assemblies are stacked first and then the two aft center segments, etc., until four segments and the forward assembly are stacked on each SRB. The forward assembly includes the forward skirt, frustum and nose cone sections, which enclose the parachute and electronics equipment. The tunnel and harnesses are then installed, connecting the forward and aft assemblies. After the ET is checked out in an ET cell, it is mated between the two SRBs and the horizontal aft struts are pretensioned with a compressive load. The SRB/ET assembly is then ready for Orbiter mate.

MATING IN THE VAB

When the Orbiter arrives in the transfer aisle of the VAB, it is fitted with lifting slings and lifted horizontally by cranes so the landing gears can be retracted and the flight umbilicals adjusted for mate. The Orbiter is then rotated to a vertical position, lifted into the vehicle assembly cell and mated to the ET. ET/Orbiter mating includes connecting and torquing the three pyro bolts in the load-carrying ball joints, attaching the left and right pyro-releasable flight umbilical assemblies, and connecting the left and right Orbiter-to-ground (tail service mast) "T-zero" umbilicals. Access platforms support ET/Orbiter mating and allow a test crew to ingress. With electrical power and other support services through the T-0 umbilicals, the Shuttle interface test is conducted to verify satisfactory integration of the Orbiter, ET, SRB, and MLP (T-0) systems. This test also verifies flight software interfaces when significant changes to software have been made. The access platforms are then retracted, and a crawler transporter lifts the MLP and Shuttle vehicle assembly to carry it to the launch pad.

LAUNCH PAD

After the MLP and Shuttle assembly are positioned on the launch pad and bolted down, the launch support systems are connected. These include the main propellant systems, water systems, ET hydrogen T-0 umbilicals, oxygen vent arm, Orbiter access arm and rotating service structure (RSS). The launch pad validation tests are performed to verify all launch support system interfaces. If a payload is to be installed vertically, it will have been positioned in the payload changeout room (PCR) on the RSS prior to Shuttle rollout to the pad. The PCR doors and Orbiter bay doors will be opened and the payload transferred into the Orbiter, mated and powered up at this time. The pad is then cleared and the hypergolic propellant systems are loaded, including all reaction control systems, orbital maneuvering systems, auxiliary power units and hydraulic power units. The pad is opened for countdown preparations and pre-count, during which cargo checks are made, the fuel cell reactant ground support equipment (GSE) dewars are loaded, and guidance and control checks and closeouts are performed. During countdown, the fuel cell reactants are loaded on board, the payload bay and PCR doors are closed, main propellants are loaded and the RSS is retracted. After inertial measurement unit warm-up, the flight crew ingresses and final countdown is initiated. During final countdown, the Orbiter access arm and oxygen vent arm are retracted. After main engine start, all three T-0 umbilicals and all SRB hold-downs are released as the SRBs are ignited and the shuttle vehicle is launched.

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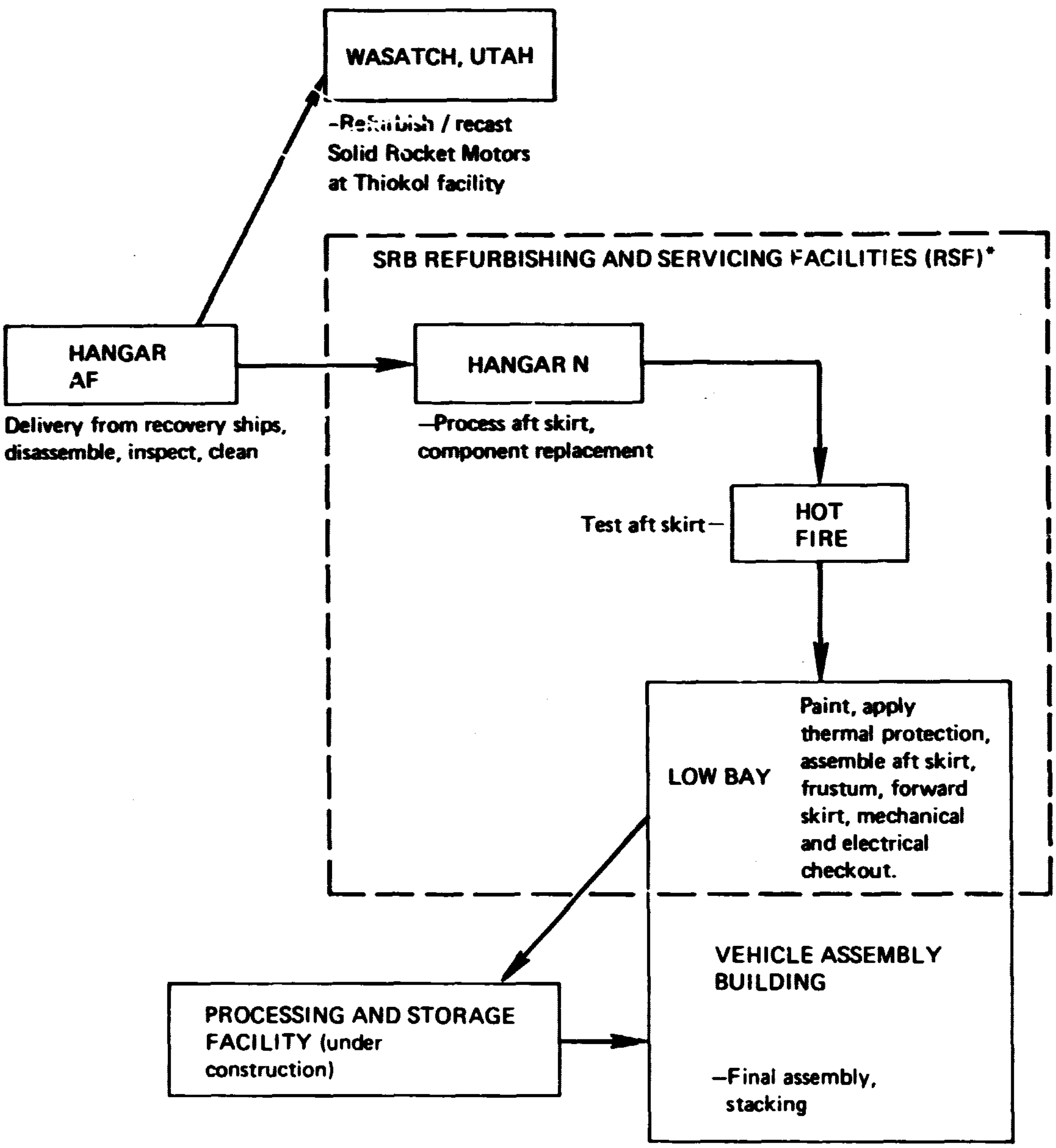
Appendix F

SOLID ROCKET BOOSTER REFURBISHING AND PROCESSING FOR FLIGHT



*A dedicated facility for RSF activities is under consideration.

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Abbreviations

APU - Auxiliary Power Units

CCAFS- Cape Canaveral Air Force Station

CoF - Construction of Facilities

CSOC - Consolidated Space Operations Center (USAF)

DoD - Department of Defense

ELV - Expendable Launch Vehicles

FPL - Full Power Level

ET - External Tank

FR - Firing Room

JSC - Johnson Space Center

KSC - Kennedy Space Center

MAF - Michoud Assembly Facility

MCC - Mission Control Center

MLP - Mobile Launch Platform

MSFC - Marshall Space Flight Center

NSTL - National Space Technology Laboratories

OPF - Orbiter Processing Facility

OV - Orbiter Vehicle

PAD - Launch Pad

PSF - Processing and Storage Facility

SCA - Shuttle Carrier Aircraft

SLA - Super Light Ablator

SMS - Shuttle Mission Simulator

SOFI - Spray on Foam Insulation

SRB - Solid Rocket Booster

SRM - Solid Rocket Motor

SSME - Space Shuttle Main Engine

STA - Shuttle Training Aircraft

STS - Space Transportation System

TPS - Thermal Protection System

VAB - Vehicle Assembly Building

VAFB - Vandenberg Air Force Base

VPF - Vertical Processing Facility